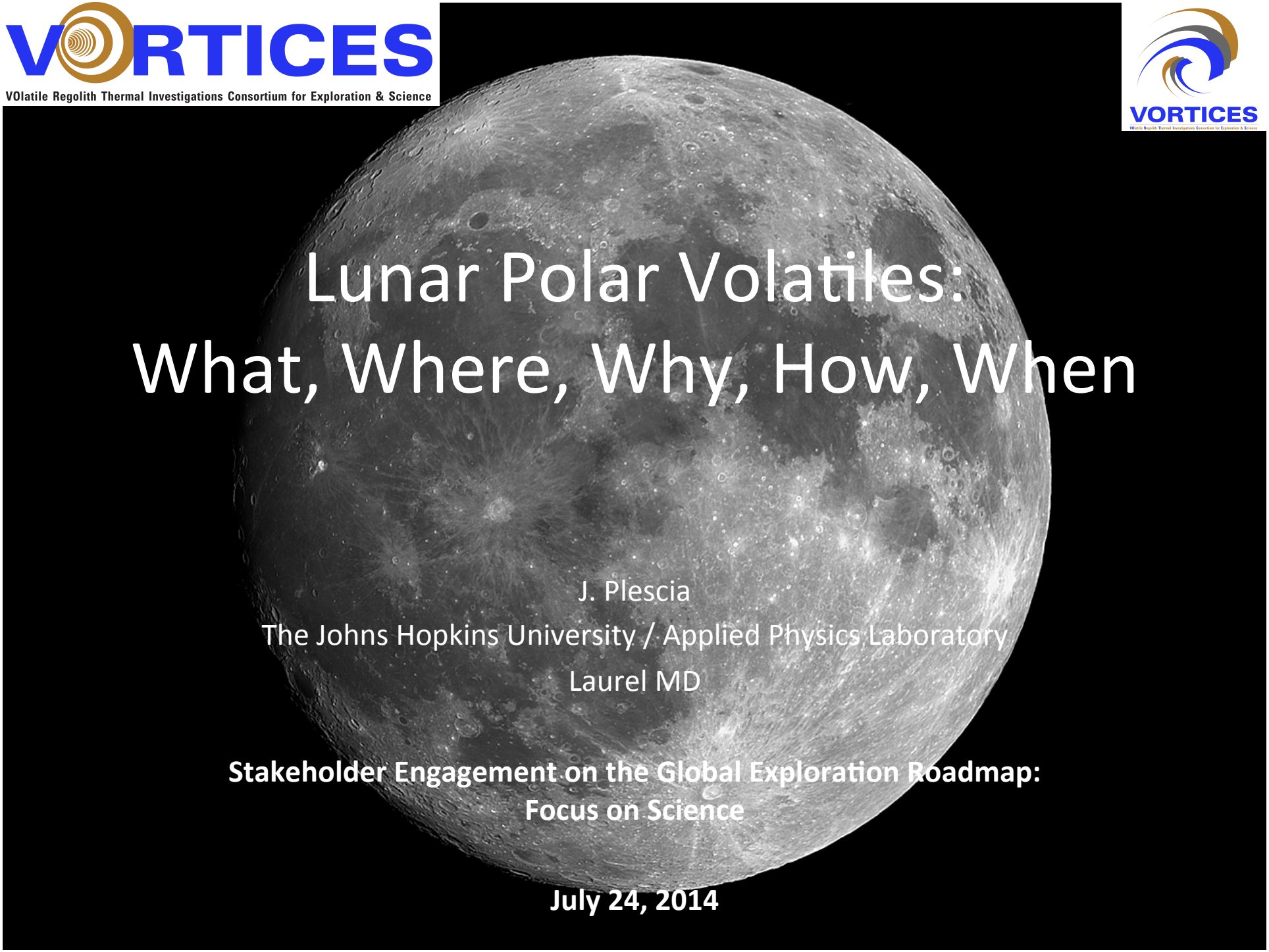
VORTICES

VOlatile Regolith Thermal Investigations Consortium for Exploration & Science



Lunar Polar Volatiles: What, Where, Why, How, When

J. Plescia

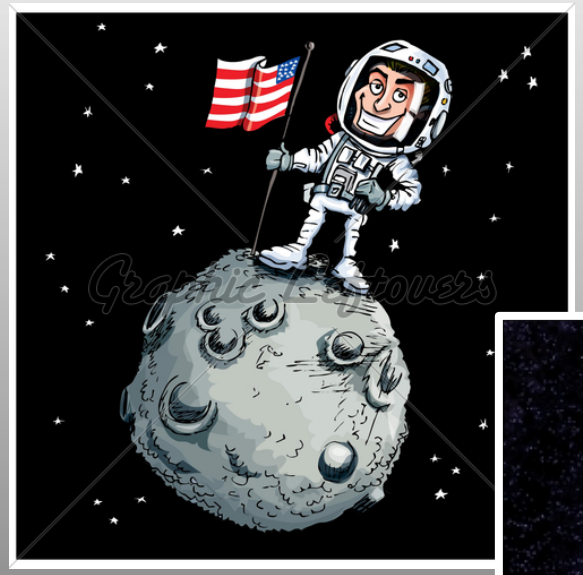
The Johns Hopkins University / Applied Physics Laboratory

Laurel MD

Stakeholder Engagement on the Global Exploration Roadmap: Focus on Science

July 24, 2014

Where Are We Going?



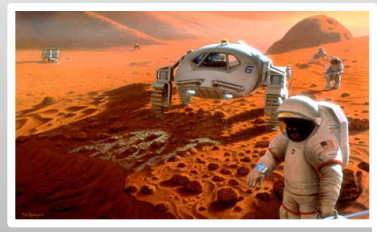
What's Our Objective in Space?

Contrary to conventional wisdom, it is *not* simply "Humans to Mars"

- That is just one of many different objectives
- Apollo-like program and architecture is likely to suffer the same type of ending

The ability to go anywhere, for any length of time, to do whatever job we can imagine

- Freedom of movement throughout the Solar System
- As long as we are limited to only what we can launch from Earth, we will remain mass- and power-limited than therefore, capability-limited
- Analogy is to seafaring, not aviation

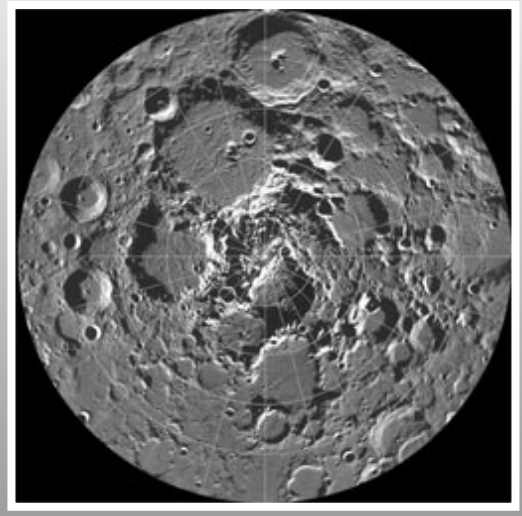


Lunar Volatiles

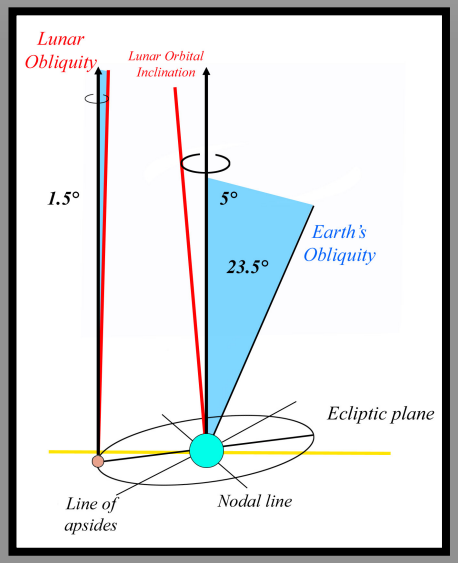
What species might be present?

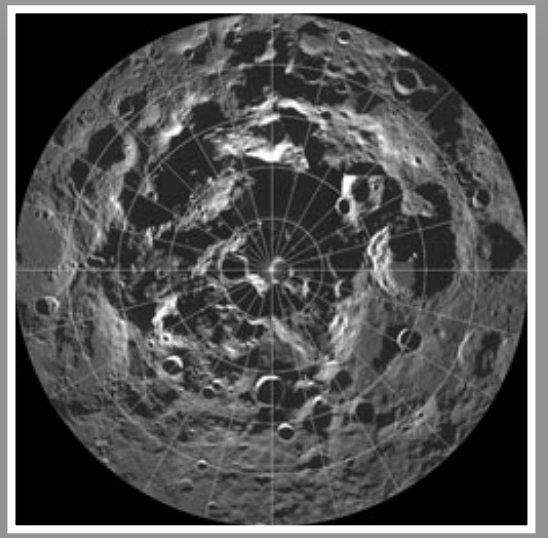
Why do we believe volatiles are present?

Where might they occur?

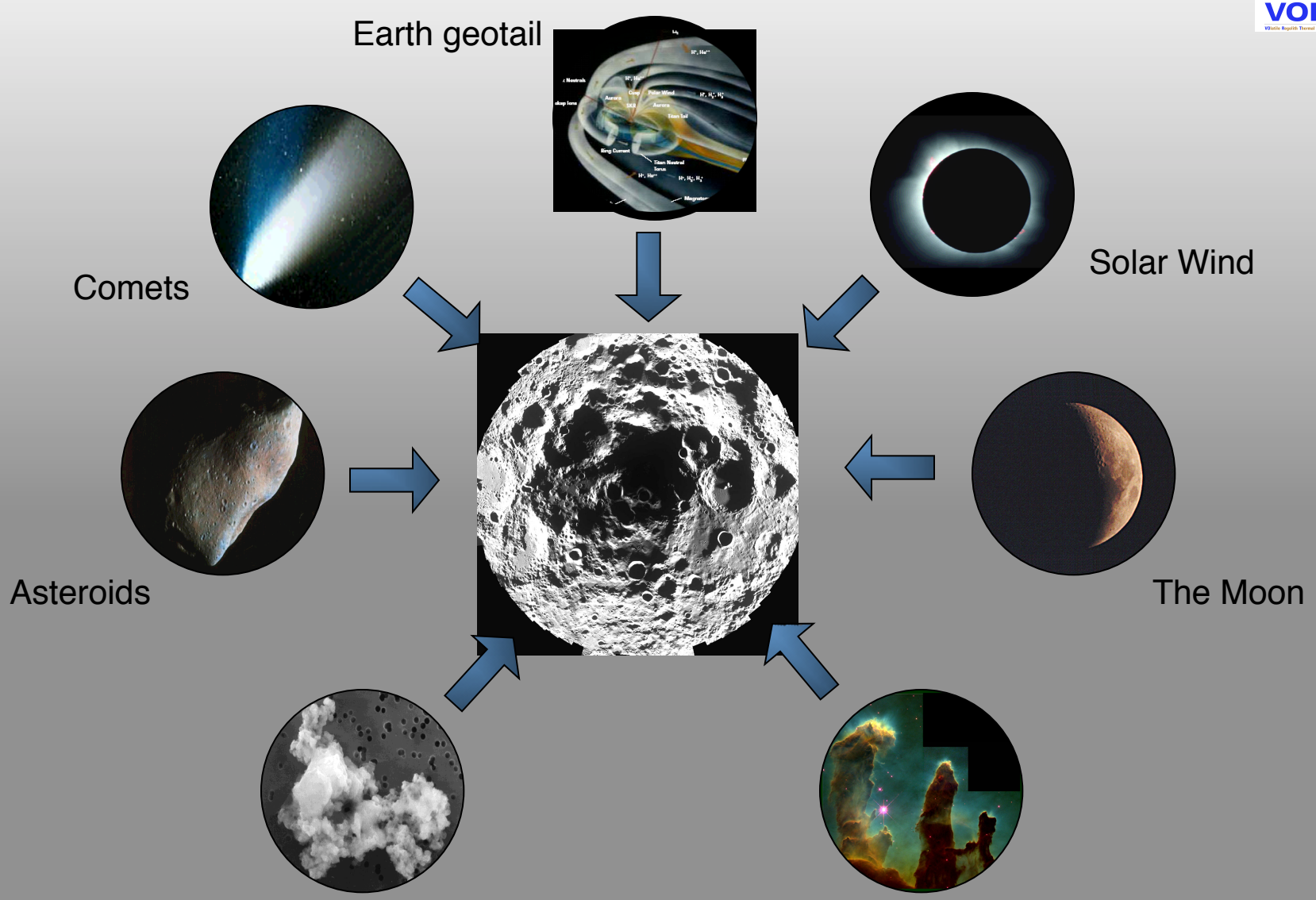


Presence originally suggested by Watson et al., 1961; Urey, 1952 based on simple consideration of the polar thermal environment.



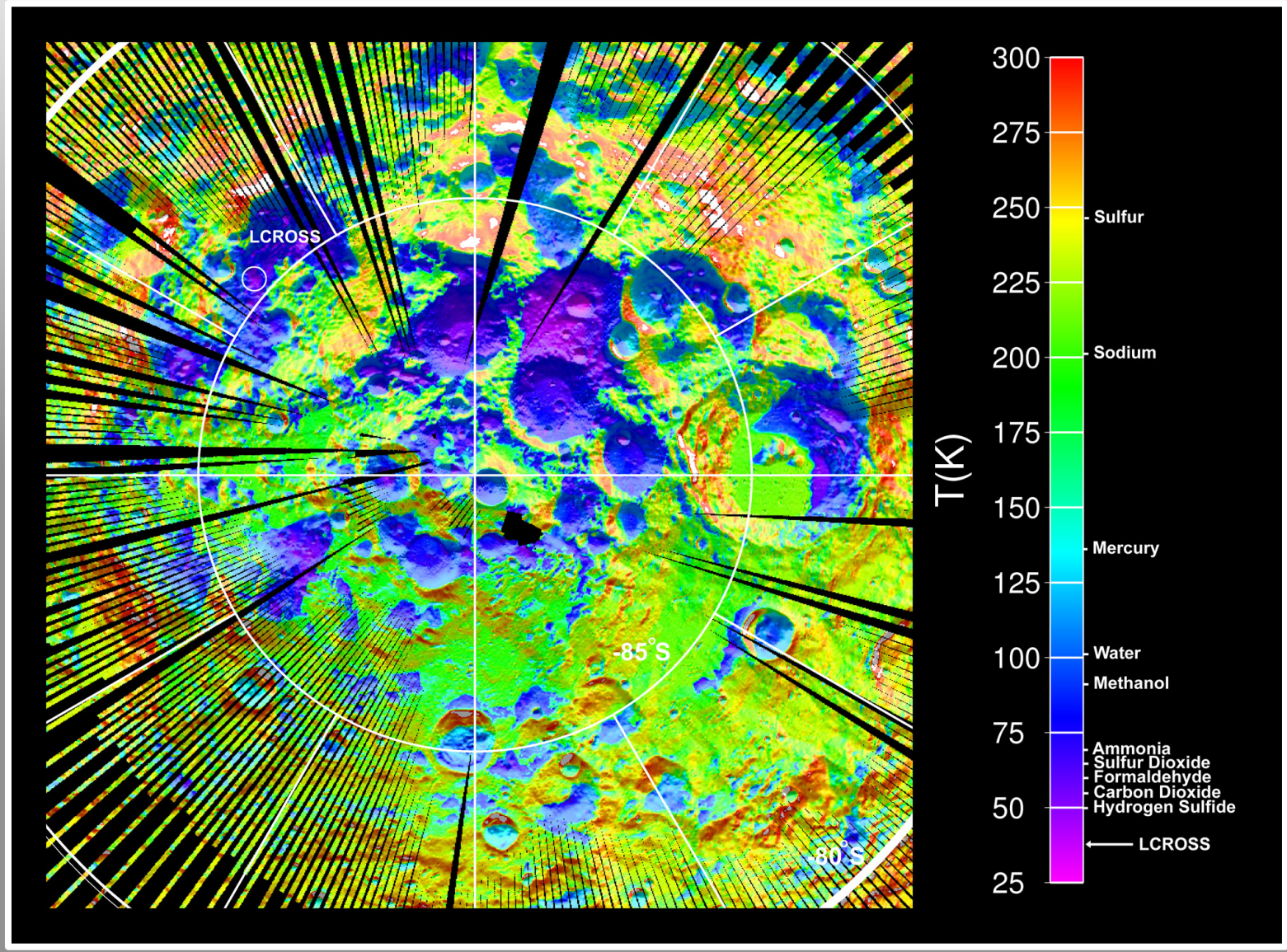


Sources of Lunar Volatiles



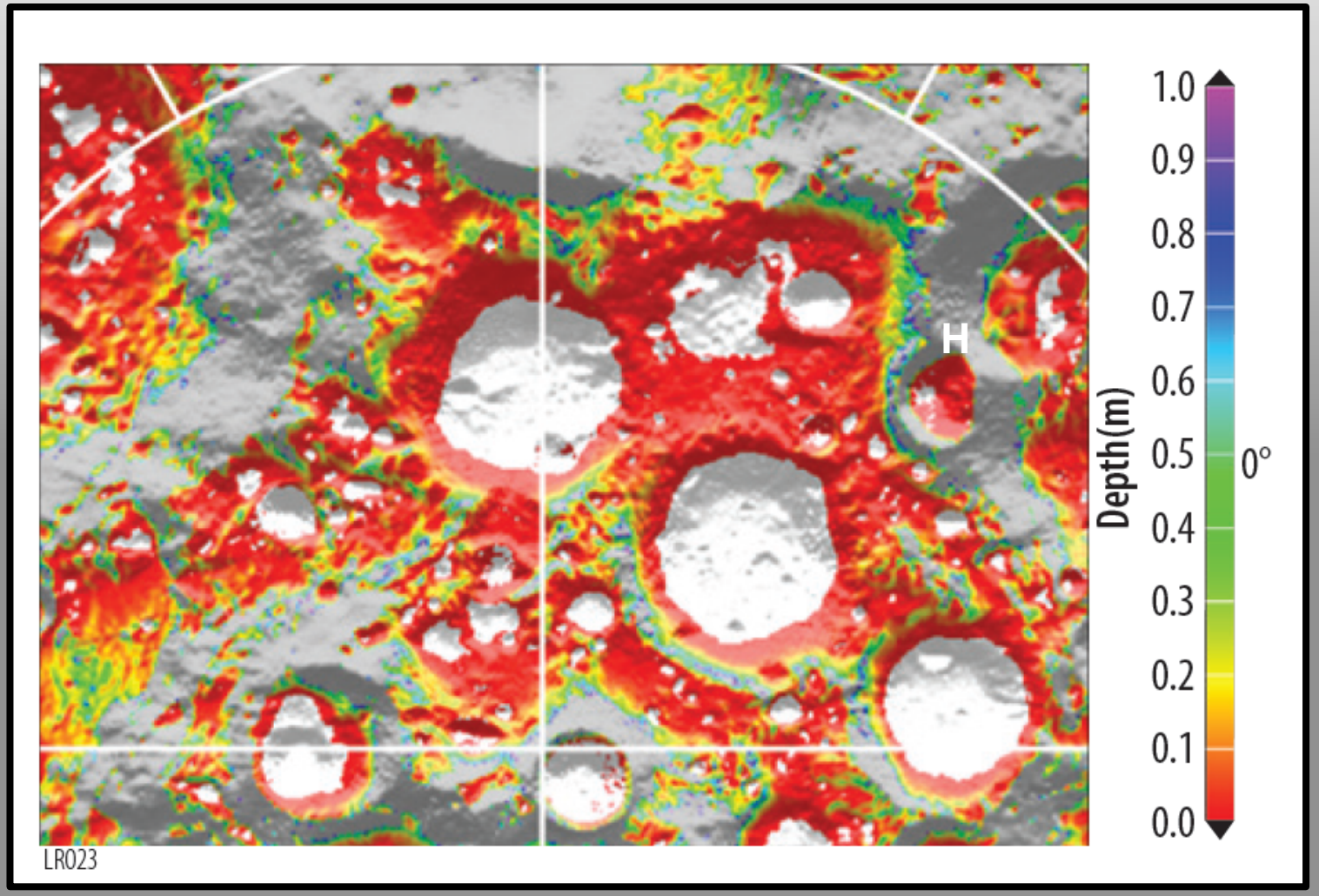
Modified from Lucey (2001)

Thermal Environment – Surface Temperature



D. Paige - Diviner

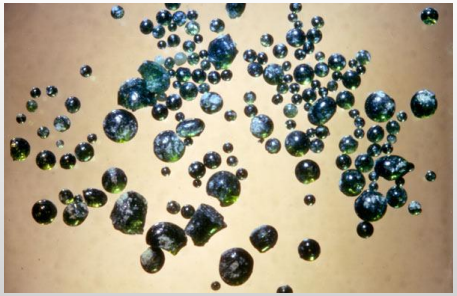
Thermal Environment – Subsurface Temperature

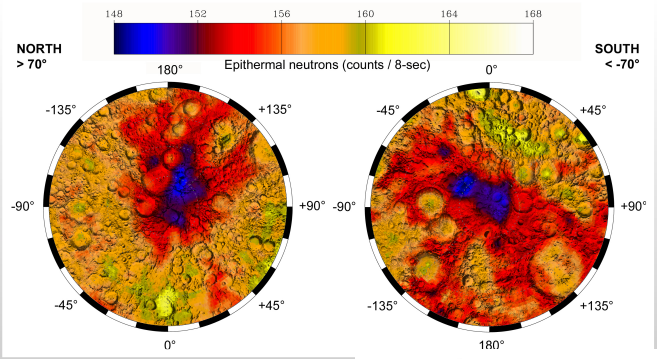


D. Paige - Diviner

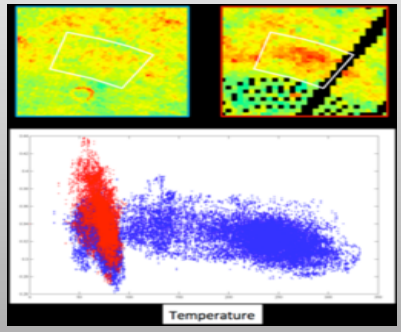
Current Understanding of Polar Volatiles

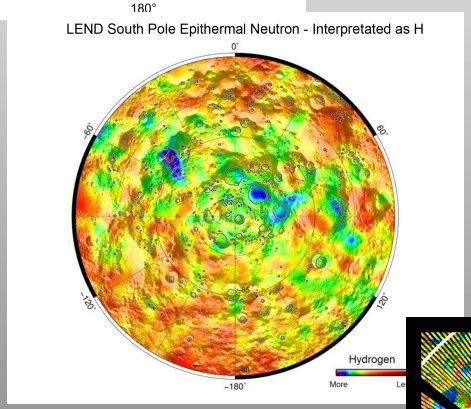
- Polar craters provide cold traps (<100K) long-term stability of volatiles / removal from exosphere
- Neutron spectroscopy (LP/LRO) indicates low epithermal neutron flux over polar areas.
  - Interpreted to be due to elevate H concentrations relative to equatorial values
  - Chemical form unknown: H could be H_2, H_2O, or maybe C_2H_5OH
- H could be widespread across polar regions or sequestered in PSR
- M3 spectral data indicate high-latitude bound / adsorbed H_2O or OH
- LOLA data suggest localized areas of higher albedo – frost?
- UVS suggests local frost
- Radar data
  - Mini-RF high CPR for some craters consistent with presence of ice
  - Solid blocks or distributed?
  - Not detected at Cabeus – monostatic, but maybe in bistatic
- LCROSS excavated Hg and water ice in Cabeus crater
- GRAIL excavated Hg from hillside
- LADEE detected H_2O and OH

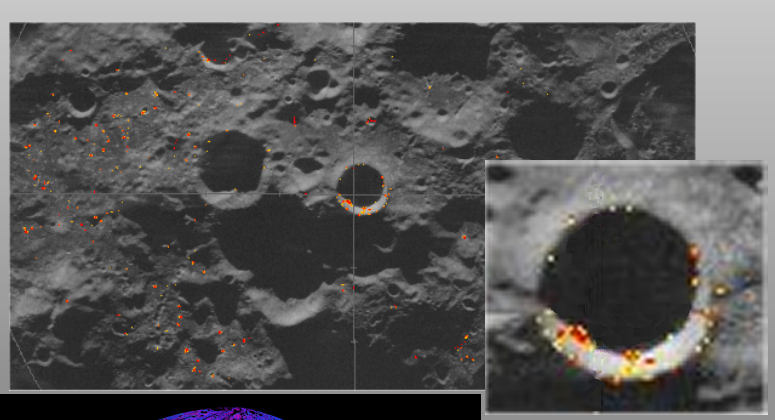


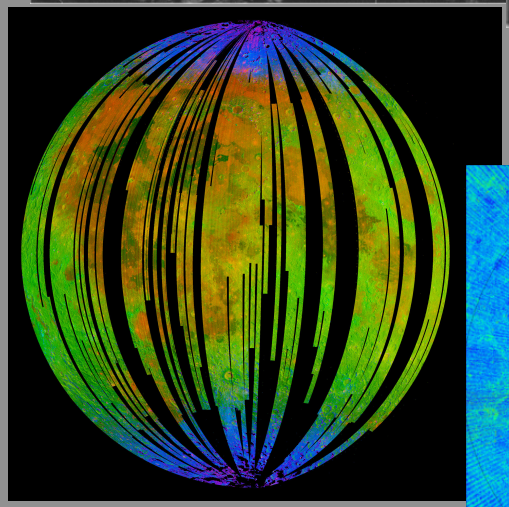

148
152
156
160
164
168
NORTH
> 70°
Epithermal neutrons (counts / 8-sec)
SOUTH
< -70°
180°
0°
-135°
+135°
-90°
+90°
-45°
+45°
0°
180°

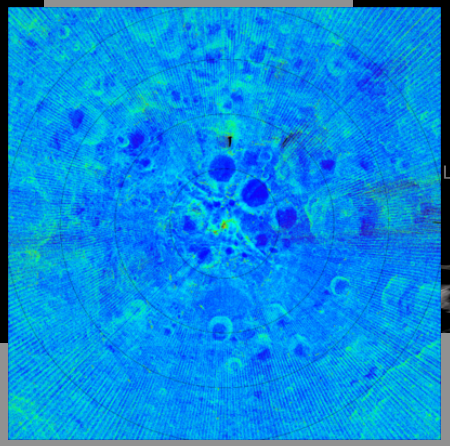

VORTICES

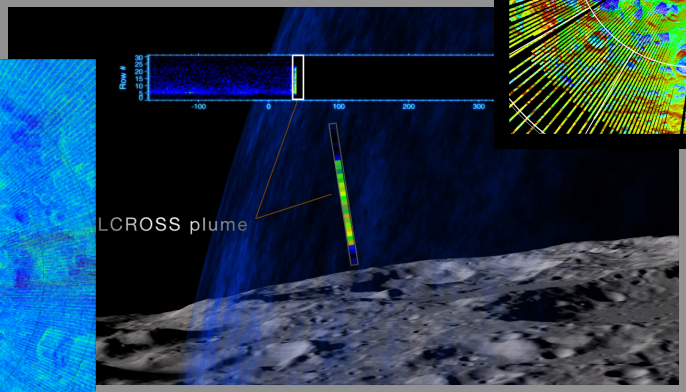

Temperature

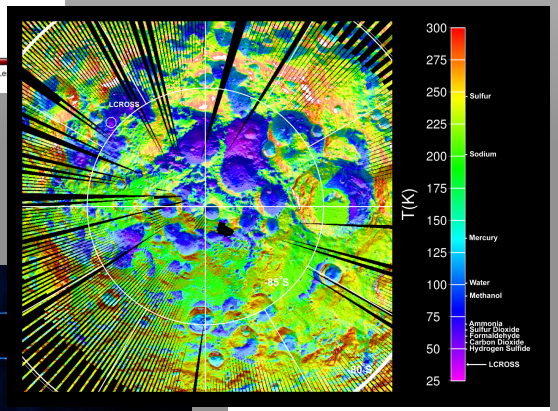

LEND South Pole Epithermal Neutron - Interpretated as H
Hydrogen
More

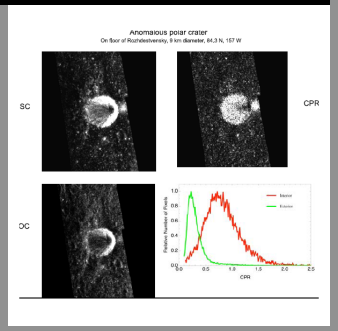







LCROSS plume


LCROSS
85 S
T(K)
300
275
250
225
200
175
150
125
100
75
50
25
Sulfur
Sodium
Mercury
Water
Methanol
Ammonia
Sulfur Dioxide
Formaldehyde
Carbon Dioxide
Hydrogen Sulfide
LCROSS


Anomalous polar crater
SC
CPR
OC

Polar Volatiles Summary

- Volatiles released (endogenic / exogenic) and formed in situ.
- Imaging / Altimetry = Areas of permanent shadow.
- LRO Diviner = It's cold.
- LP / LEND data = H at shallow depth below the surface – may not be confined to PSR, may not be water.
- Apollo / LCROSS /GRAIL = H_2O and Hg in surficial materials.
- M3 = H_2O, OH on surface.
- LAMP/LOLA = Local H_2O frost on surface.
- Clementine / LRO / Arecibo radar = H_2O ice in blocks (~0.5-1.0 m blocks, not frost).


WE HAVE INCOMPLETE DATA, SO I'LL NEED TO USE MY INTUITION AND EXPERIENCE TO MAKE THE DECISION.
Dilbert.com DilbertCartoonist@gmail.com
BECAUSE MAGICAL THINKING FIXES IGNORANCE?
7-22-14 © 2014 Scott Adams, Inc./Dist. by Universal Uclick
HUSH! I THINK I HAVE SOME-THING.
I THINK SO TOO.

Now What?

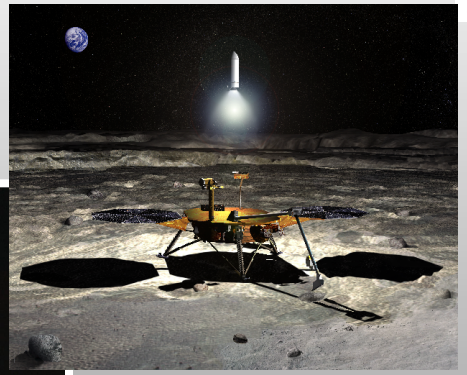
- Do not understand the species.
- Do not understand the vertical / lateral distribution.
- Do not understand form (e.g., solid ice, frost, ice-cemented regolith, surface frost).

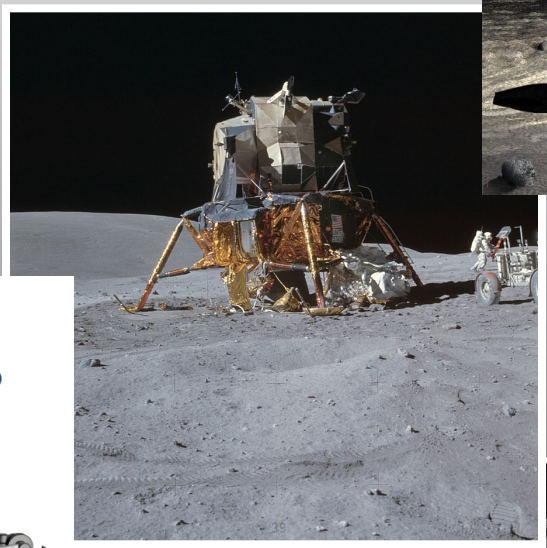
- We do not understand the process of volatile introduction / sequestration.
  - Comet impact
  - Solar wind
  - Kinetics at 40K are slow

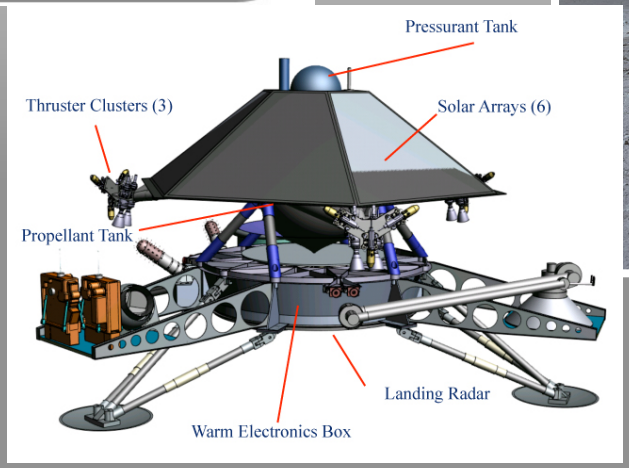
- These are required to make a decision on the ore and location.

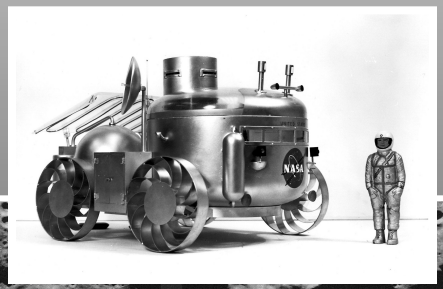
Now What?

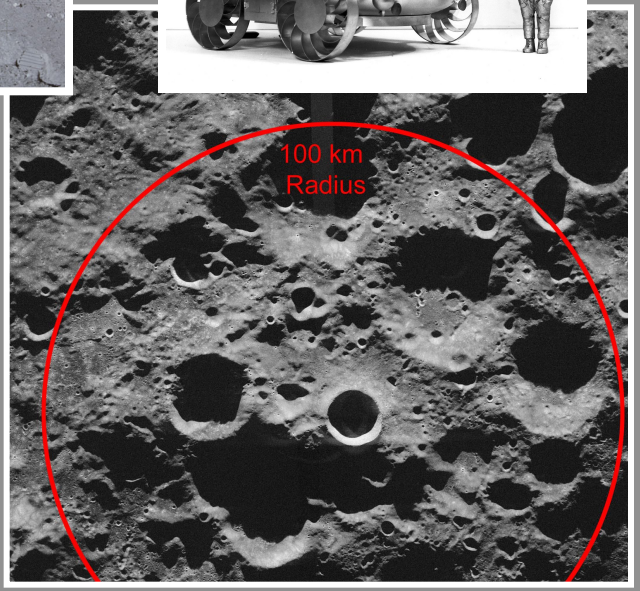

Courtesy of OHB-System AG

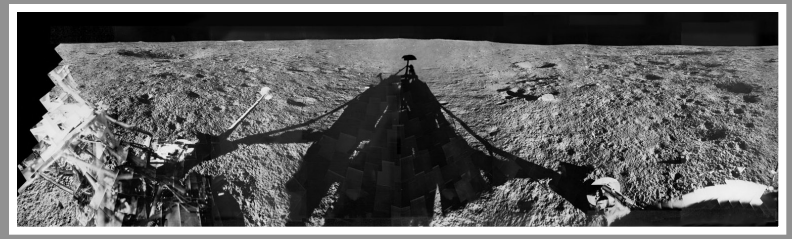





Pressurant Tank
Thruster Clusters (3)
Solar Arrays (6)
Propellant Tank
Landing Radar
Warm Electronics Box

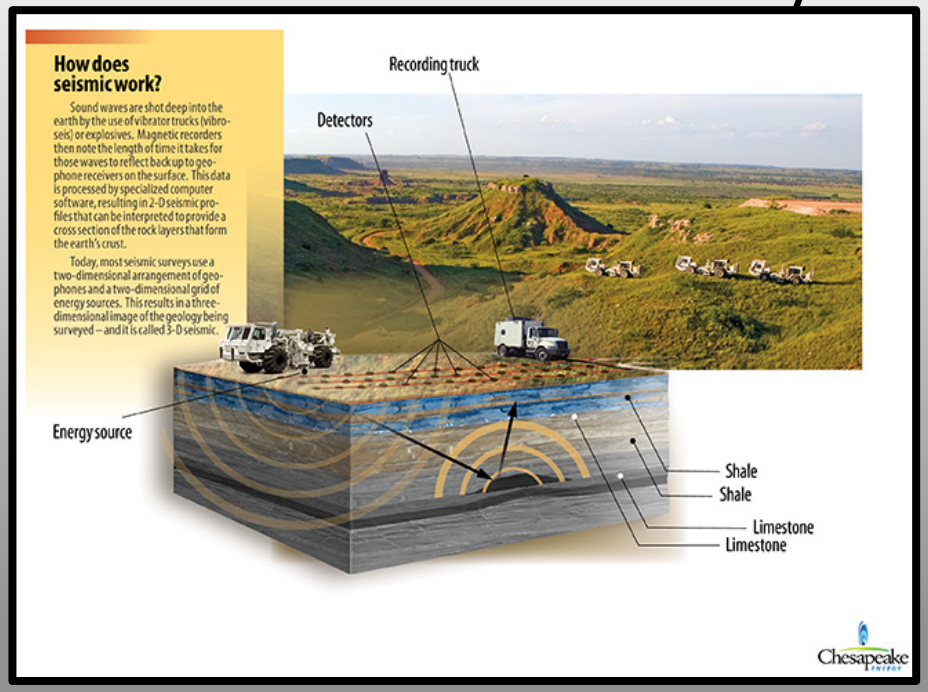


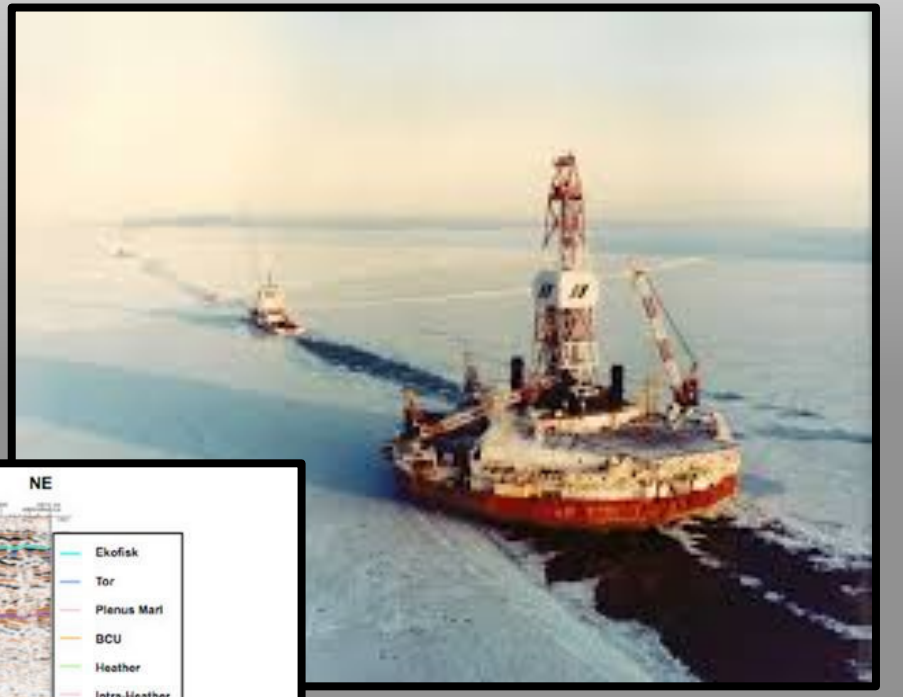

100 km
Radius

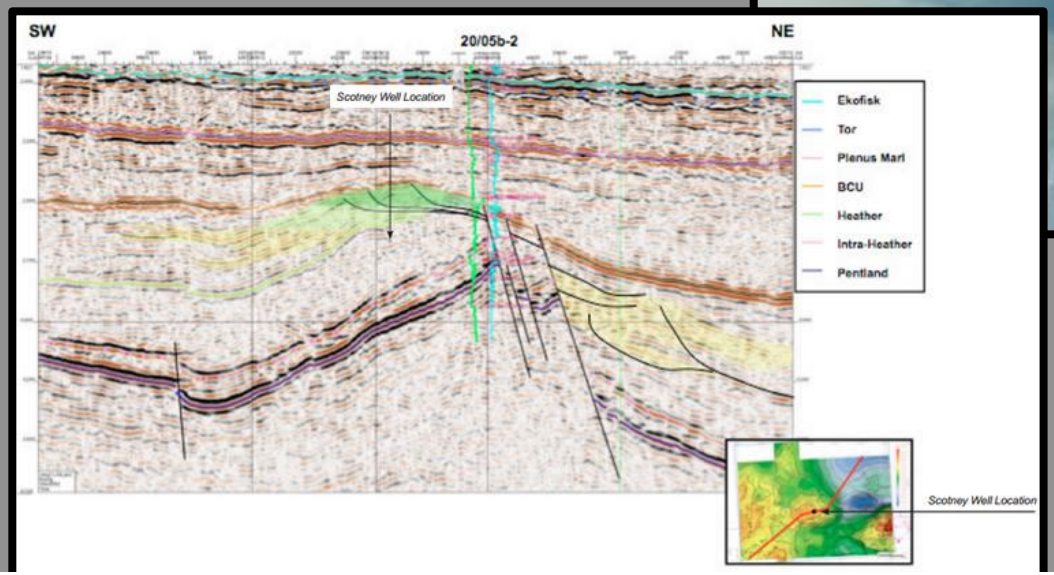



CURMUDGEON

What Does it Really Take to Find A Resource?







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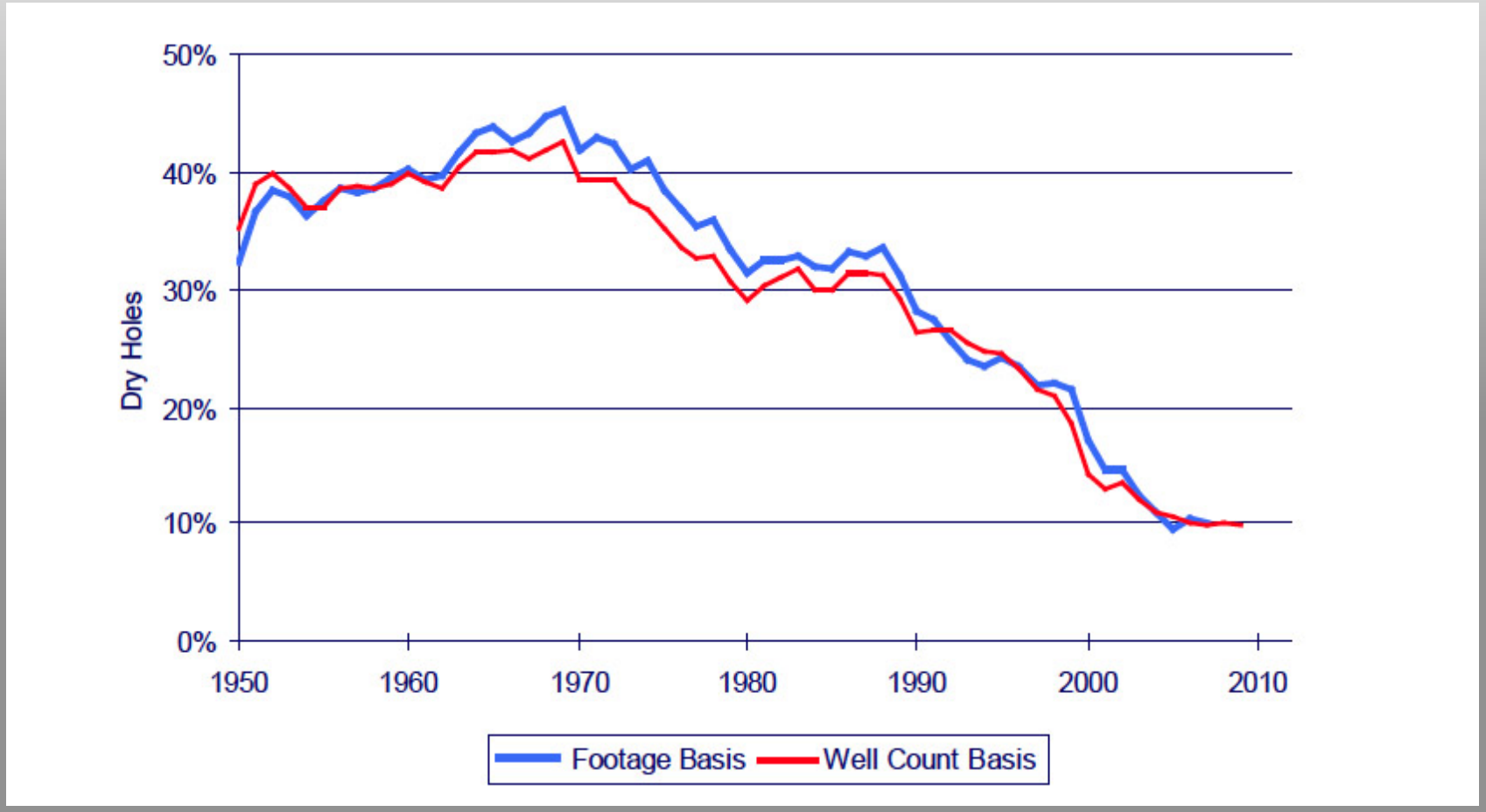
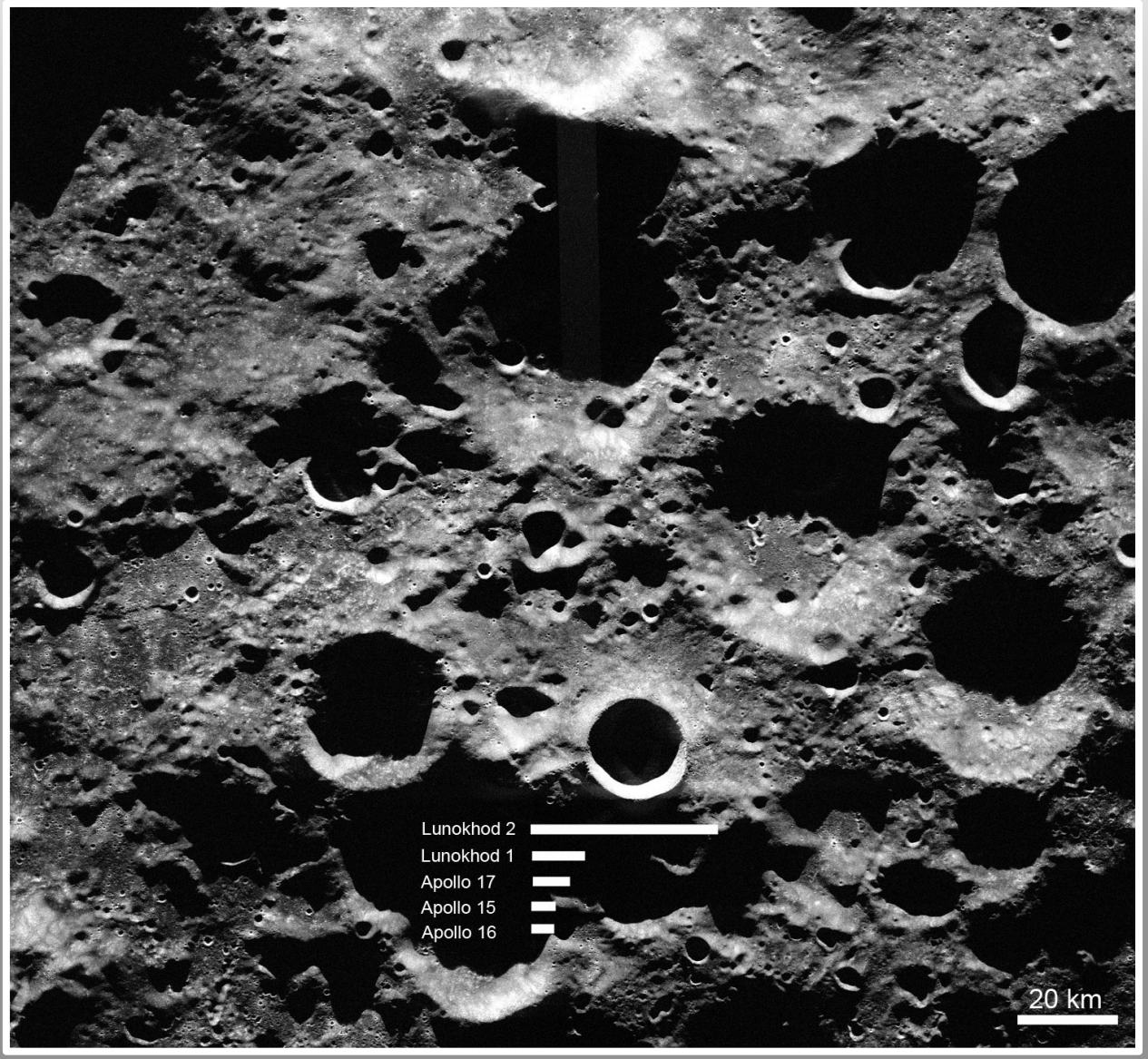


First oil well 1859

US Energy Information Agency

What Does it Really Take to Find A Resource?

Sojourner:	36 m/hr
Curiosity:	90 m/hr
MER:	180 m/hr
Lunokhod 1:	800 m/hr
Lunokhod 2:	800, 2000 m/hr
Apollo LRV:	<10000 m/hr
Garden Snail:	47 m/hr
Lunokhod 2:	37400 m
Lunokhod 1:	10540 m
Apollo 17:	7400 m



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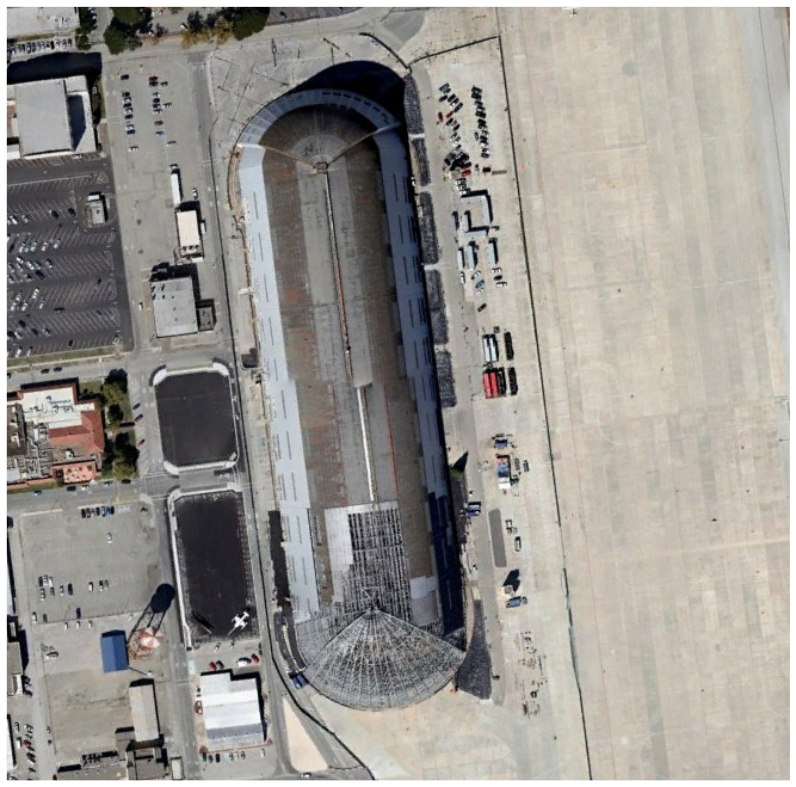


Future Mission Activities

Mission Activities (planned – dates and final configuration may change):

2015

- Google X-prize – commercial lander / rover
- Chang'E 4 – Chinese lander / rover
- Chandrayaan-2 – ISRO orbiter / lander / rover
- Chang'E 5 – Chinese sample return
- Luna-Glob 1 – Roscosmos orbiter / penetrators
- Luna-Glob 2 – Roscosmos lander / rover

2017

- Kaguya-2 (SELENE-2) – JAXA lander / rover / penetrators?
- Resource Prospector Mission (RPM) – NASA lander / ISRU demo

2020

- SELENE-3 – JAXA sample return
- Luna-Grunt(s) – Roscosmos lander / rover / sample return

2025-2030

- Chinese Human Landing

Possible Mission Near-Term Mission Results / Implications

Water ice in sample (<50 cm depth)

- Rover in the light to prospect, extract and process the ice

Analysis and Neutron Data indicate Apollo hydrogen quantities

- Permanent shadow rover

Enhanced Hydrogen Analytic & Neutron (>> Apollo, consistent with orbital neutron data)

- Rover in the light to extract H from regolith and O from silicates

No hydrogen in any form

- Permanent shadow rover

Nominal Hydrogen Analytic, enhanced Neutron, no ice

- Rover in the light to prospect for water ice
- Permanent shadow rover to search for ice

The next step depends on the use of the resource.

Exploration Rover Objectives (Sunlight / Shadow)

- Determine form and species of volatiles (H or H_2O)
  - Presence and physical state (ice frost, ice-cemented regolith, solid ice)
  - Species (e.g., H_2O, OH, CH_3OH, C_2H_5OH, NH_3, SO_2, CH_2O, CO_2, H_2S, CS_2, Hg, C_2H_5OH)
  - Determine the isotopic composition (e.g., CHONPs)

- Determine the vertical distribution of volatiles.
  - Vertical scales of 1-2 m

- Determine the lateral distribution of volatiles.
  - Lateral over scales of 100s – 1000s m
  - Continuous vs. patchy

Prioritized Capabilities

Exploration Rover

Neutron spectrometer: Locate H, lateral distribution, identify sampling sites

Sample acquisition system: Acquire a sample (aka – drill)

EGA / GS: Volatile species

Down hole micro-camera: Form of volatile

EM sounding: Lateral distribution of ice

Mass spectrometer: Isotopic composition

XRD, Mossbauer: Alteration mineralogy

Mass spectrometer: Exosphere - might be same one as above with different port

Resource Extraction

Regolith collection / processing

1a. Hydrogen release by heating

Storage of hydrogen

Transfer of hydrogen

1b. Cracking of silicate minerals to release oxygen

Storage of oxygen

Transfer of oxygen

2. Water released by heating

Cracking of water

Storage of hydrogen and oxygen

Transfer of hydrogen and oxygen

Exploration Rover Characteristics

- 500 kg class-rover (including payload)
- LIDAR/optical based navigation
- Earth communication: DTE or via lander or comsat
- Speed ~ 2 km / hr

- Power
  - RTG, fuel cells, primary battery, solar*

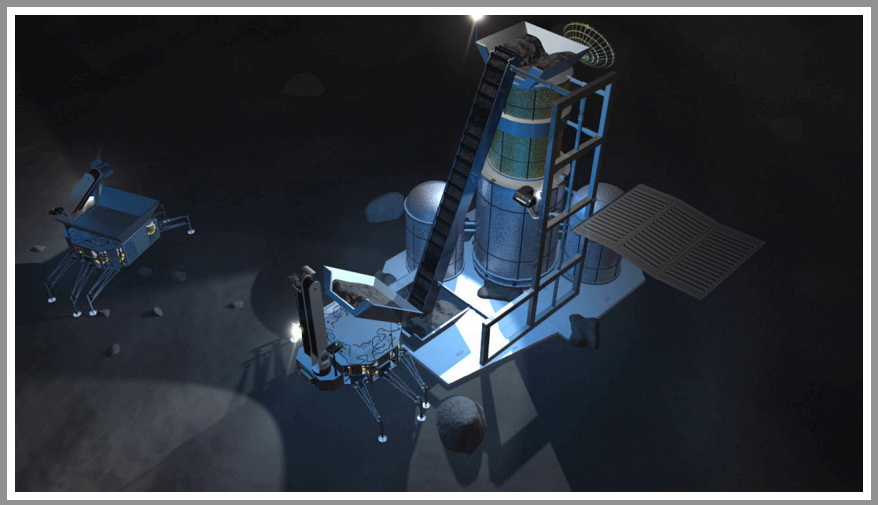
- Potential Payload
  - Neutron Spectrometer: 1 kg
  - Drill: 15 kg
  - Sample handling: 15 kg
  - MS/EGA: 3 kg
  - EM probing: 3 kg
  - Chemistry/mineralogy: 4 kg

ISRU Demonstration / Regolith Excavation

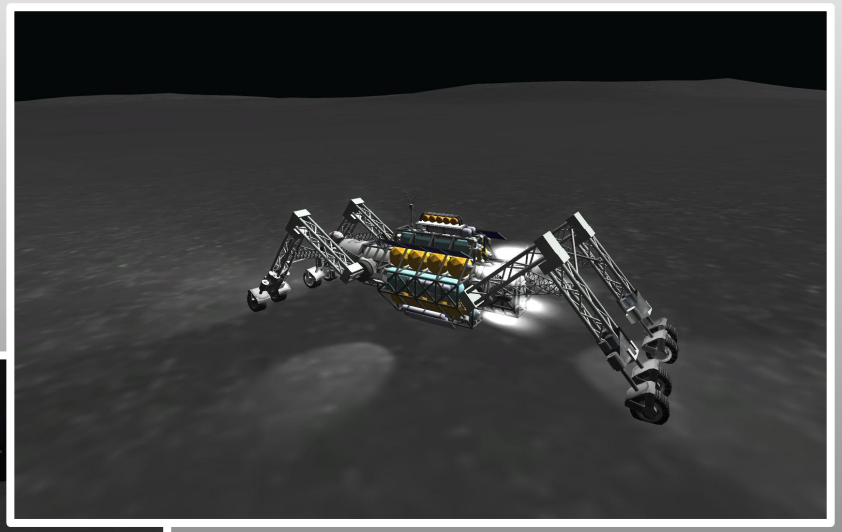
Demonstrate

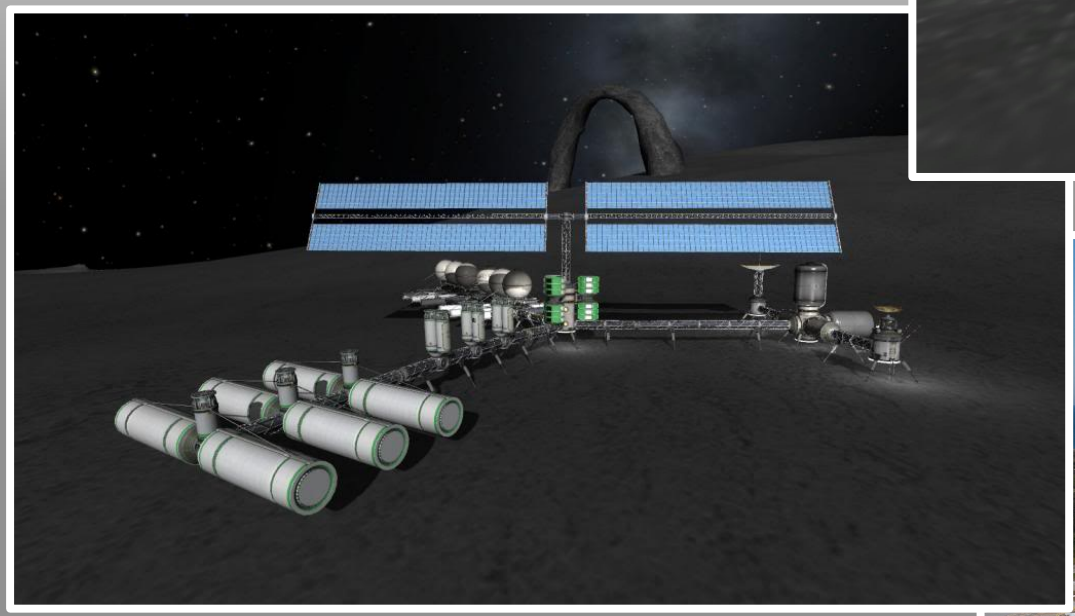
- Excavation and transport
- Recovery of volatiles
- Cryogenic storage and transfer

Requires advanced power, mobility, large landed payload capacity



Processing, Storage, Use





Conclusions

- H is present in polar regions in enhanced concentration – but details of distribution and form are unknown.
- Before a decision is made regarding the use of the resource and what the resource would be – additional information is needed.
- Depending upon the results in the sunlight, exploration in PSR may or may not be needed.
- To fully characterize the vertical and lateral distribution, mobility is required.
- Demonstration of collection, processing, storage, use is required.